Coarse scale fire history in relation to macroclimatic precipitation in the greater Columbia river basin, ca. 1500-1940 A.D.

COARSE SCALE FIRE HISTORY IN RELATION TO MACROCLIMATIC PRECIPITATION IN THE GREATER COLUMBIA RIVER BASIN, ca.1500-1940 A.D.

May 1995

Stephen W. Barrett[1]

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[1]Research Forester with Systems for Environmental Management, Missoula, MT. Final report for Part I of Research Joint Venture Agreement INT-92676-RJVA between S.E.M. and USDA Forest Service Intermountain Research Station. (Part II, "A Fire Regimes Database for Coniferous Forests in the Inland Northwest", is on file at USDA Forest Service Intermountain Fire Sciences Laboratory, Missoula MT).

2 copies

31 May 1995

Jim Brown, Project Leader
Intermountain Fire Sciences Laboratory
Missoula MT

Dear Jim,

Enclosed is the final report and database in completion of Research Joint Venture Agreement INT-92676-RJVA: Part I refers to "Coarse Scale Fire History in Relation to Macroclimatic Precipitation in the Columbia River Basin, ca. 1500-1940 A.D.", and Part II refers to "A Fire Regimes Database for Coniferous Forests in the Inland Northwest".

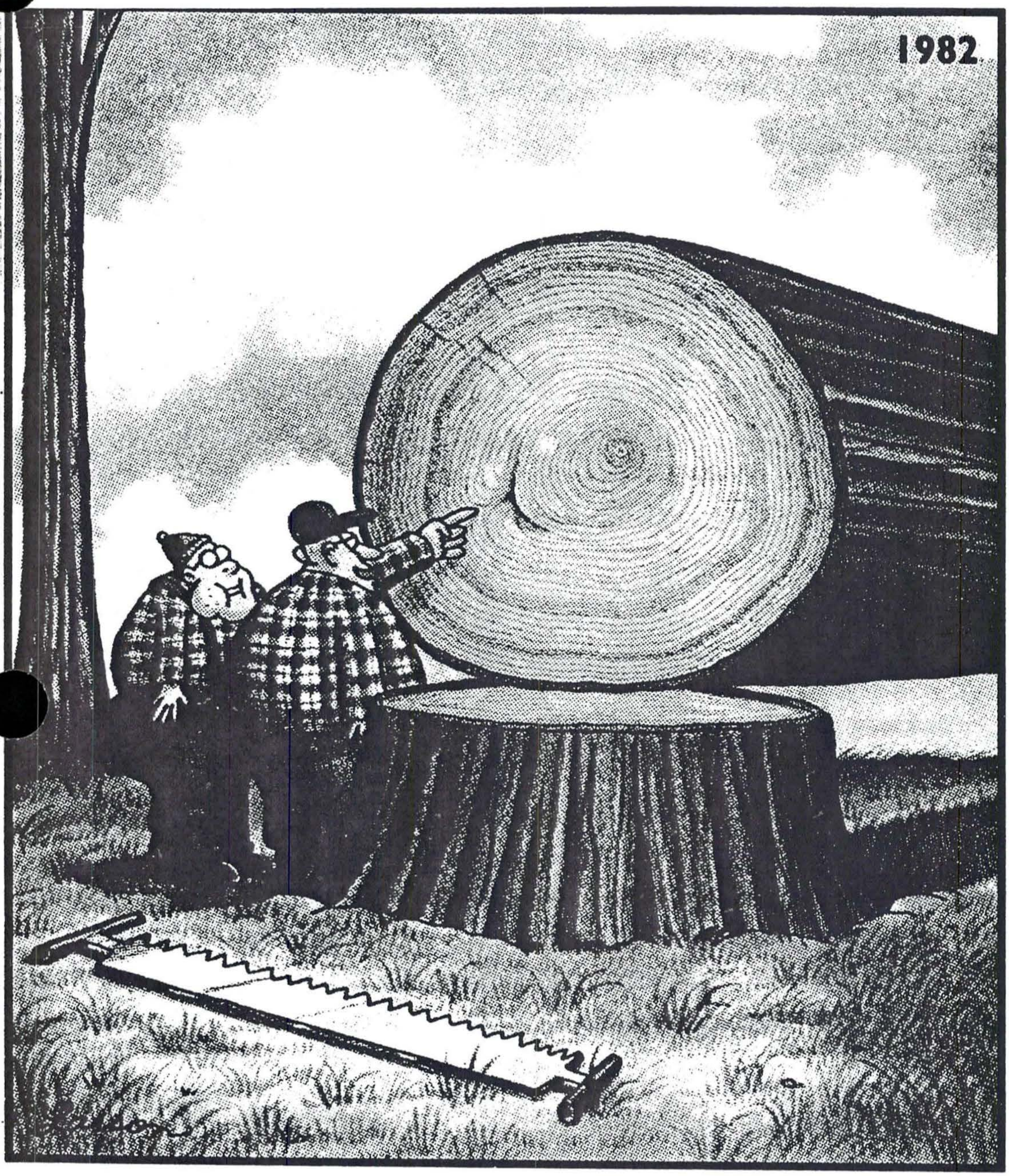
Subsequent to your final approval, S.E.M. will bill Ogden for final payment on this RJVA.

I have enjoyed working with you and your personnel on this project, and look forward to subsequent revisions of this work for possible publication.

Sincerely,

Stephen W. Barrett
Research Forester
S.E.M.

Fig. 1a. Arno & son in pursuit of "truth".



"And see this ring right here, Jimmy? ...
That's another time when the old fellow
miraculously survived some big forest fire."

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INTRODUCTION

Ecologists and professional foresters are well versed on fire's vital role in ecosystem processes and distribution in western North America (Pyne 1982). However, the public is less well informed in this regard, and has often criticized land management agencies for failing to predict and prevent severe wildfires, such as in 1910, 1988, and 1994. Moreover, much of the public now has the perception that traditional management activities, such as fire suppression and timber harvesting, have enhanced fire hazards by causing unprecedented fuel buildups in many western forests. Such issues generate much political controversy, but the resultant policy debates are myopic when they lack a sound scientific- and historical basis. For example, even cursory examinations of fire history data have suggested that forest fires occasionally were widespread before 1900.

Long-term fire history chronologies have been produced for numerous forested sites in the greater Columbia River basin (CRB)(Mastrogiuseppe et al. 1983, Heyerdahl et al. 1994, Barrett 1995). Similarly, the patterns of macroclimatic precipitation during the last 700 years in the greater CRB have been well studied (Keen 1937, Laephart and Stage 1971, Karl and Koscielny 1982, Graumlich 1987, Meko et al. 1993). To date, however, no attempts have been made to develop a regional context of fire history, nor have investigators examined the possible relationship between macroclimate and coarse scale fire history. Such information would be useful for a host of scientific and land management concerns. For example, because the level of synchronization between cyclical droughts and coarse scale fire history is largely unknown, it is unclear whether important fire years have occurred on a regional- or a primarily subregional basis. Severe droughts and a possible trend toward global warming in the late 20th century

make this issue important--particularly in light of on-going land management controversies. To gain broader insight into these and other related questions, the following study was conducted to develop and analyze a comprehensive database of pre-1940 fire history information for the last 4 centuries in the greater CRB.

OBJECTIVES

Study objectives were to:

1. Review published and unpublished fire history studies in the CRB and peripheral areas and compile a database of estimated pre-1940 fire years and other site data.
2. Analyze regional fire history in terms of the approximate frequency and distribution of fires, with the data delineated according to geographic location, fire severity type, and fire occurrence relative to macroclimatic precipitation.

METHODS

Data Collection. A literature search was conducted for all published fire history studies in the greater CRB, including in the Canadian Rockies and extreme northeastern California. Ecologists in the region also were contacted to acquire copies of any unpublished fire history data. Master fire chronologies and associated latitudinal- and longitudinal coordinates were obtained for each study area, which ranged in size from single points on the ground (e.g., one fire scarred tree) to comparatively large areas encompassing multiple drainages. One fire record was entered in the database for each fire year in a given area fire chronology, regardless of the number observations in that area. Major site fire years also were noted--a subjective assessment,

by the original researchers or by this author, of whether a given fire had been appreciably larger than most other fires in an area chronology. The rating was possible only for relatively large study areas (e.g. 10,000+ acres). Although inherently weak, these data were examined in relation to results for overall fire frequency, to possibly help identify major fire years at the coarse scale.

Fire history studies provided most of the information in the database, but fire atlases, newspapers, and other early-day accounts of past fires also were reviewed on an opportunistic basis. For instance, data entries were made for any substantial fires (e.g., 50+ ac.) in readily available fire atlases. Entries also were made for noteworthy forest fires that were described by early-day travellers or newpapers, as opposed to, for example, frequent Indian-caused fires (Barrett and Arno 1982, Gruell 1985). When precise location information was lacking, or, when a given wildfire had been very extensive, a central geographic location was selected as representative.

Database Structure. The following classes of data were entered into dBASE III Plus database files (i.e., "RFIREYR.dbf"and "RFIREPUB.dbf", enclosed with this report):

REF: Database reference number.
STUDY: Author/date format.
PUB: Published; unpublished; thesis.
REGION: (Note: the following custom-defined subregions east of the Cascade crest do not necessarily correspond with those in other geographic classifications).

NWM (northwestern Montana); WCM (w. central Mont.); SWM (s.w. Mont.); CEM (central Mont.); SCM (s. central Mont.); SEM (southeastern Mont.); NID (northern Idaho); CID (central Idaho); EID (e. Idaho); SID (s. Idaho); NWW (northwestern Wyoming); NEW (northeastern Washington); SCW (s. central Wash.); WCW (w. central Wash.); EOR (e. Oregon); SCO (s. central Ore.); WCO (w. central Ore.); NCA (northern California); ALT (Alberta); BC (British Columbia).

SITE: Narrative description of site location.
LAT/LONG: Latitudinal- and longitudinal coordinates (degrees/minutes).
VEGTYPE: Society of American Forester (1980)(SAF) codes for primary, secondary, and tertiary forest cover types in the study area.
FIREYR: Each estimated fire year in the master fire chronology.
MAJORYR: True or false.
SOURCE: Year estimated from scars, fire initiated age classes, or written records.
LETHALITY: Primary fire severity type in the master fire chronology (nonlethal- vs. lethal [i.e., mixed- and stand replacement]).

Assessment of Database Accuracy. Because of the wide array of data sources, and the expansive analysis area, only limited accuracy can be attained in estimating regional fire history for the last 400 years. Accuracy ranges widely between the various sources--from precise written records (e.g., maps, diaries) to mere rough estimates of site fire years based on post-fire seral age classes. Even when comparatively-reliable fire scars were sampled, most investigators did not use dendrochronological cross-dating (Stokes and Smiley 1968). Likewise, study quality varies widely, depending on such factors as investigator qualifications and experience level, study comprehensiveness (i.e., available time, effort, and resources), and the inherent level of difficulty of interpreting fire history in certain forest types. Even well known historic fire years, such as 1889 and 1910, have been under- or overestimated, particularly when interpretations were based solely on age class samples. Correction to known fire years often is feasible (Arno and Sneck 1977, Barrett and Arno 1988), but can be totally inappropriate for ponderosa pine (*Pinus ponderosa*) stands, where date clustering might indicate several closely spaced fire years.

In uncrossdated studies of frequently burned ecosystems, such as ponderosa pine stands, the most likely sources of error are: 1) scar ring count errors, 2) scar misidentification, 3) incorrect scar year adjustment, and 4) incorrect correlation of estimated fire scar dates within

and between stands (Arno and Sneck 1977, Madany et al. 1983). Imprecision can result both for individual fire years and for the total number of fires in a chronology, and further, these errors can have a multiplier effect in large study areas. Consequently, the database for the nonlethal fire regime might reflect somewhat more frequent fires than actually occurred (in this investigator's experience, errors are more often skewed toward overestimating, rather than underestimating, fire frequency). There are fewer potential sources of error in studies of less frequently burned forests, for example, in the mixed severity- and stand replacement fire regimes. But fire year estimates often are less accurate because interpretations often are derived from age class samples alone. Therefore, although estimated fire frequency for the lethal fire regimes may be more accurate than for the nonlethal group, the fire year estimates may be less precise.

The multitude of variables above thus make it impractical to readily identify and control potential sources of error in the database. Because it was not possible to attain any appreciable measure of control over fire year accuracy, most of the original fire year estimates were accepted at face value. In rare instances, however, raw data were re-analyzed to reduce apparent levels of error. Any potentially useful data that seemed to be of comparatively low quality were adjusted (Arno and Sneck 1977, Barrett and Arno 1988) when the raw data suggested that the original investigator had interpreted too few or too many fire years. When a cluster of closely similar estimated fire years suggested one rather than multiple fire events, then the most frequently observed year in that cluster was used to represent the fire year. Conversely, the midpoint value was used when dates were relatively equally distributed within the cluster. Also, some fire atlases and fire history studies had described only decadal fire history (e.g., one fire between

1850 and 1860). In such cases, the mid-decade year (e.g., 1855) was used to represent the fire year. In summary, because it was infeasible to identify and cross-correlate actual fire years among and between numerous study sites in the greater CRB, the alternative was to analyze period fire frequency (described below).

Data Analysis. Because of the numerous uncontrollable variables in this study, descriptive statistics alone were used to describe fire frequency and other elements of the fire history database. Initially, the following basic attributes of the database were analyzed: distribution of fire year data according to location, forest cover type, fire severity type, data source (e.g. fire scars, written records), and other attributes.

Fire frequency was analyzed as follows. Studies (Arno and Sneck 1977, Madany et al. 1983, Barrett and Arno 1988), as well as this investigator's extensive experience in analyzing fire history, suggest that many fire year estimates are within ~~5 years~~ a few years of a actual site fire year. Therefore, a "running" 5-year tally of fire year estimates was conducted, beginning with 1500 $\pm$ 2, 1501 $\pm$ 2, 1502 $\pm$ 2, and so on, up to 1940. A running tally reduces the effect of estimation errors by smoothing the annual frequency curve, more accurately portraying fire frequency variation between consecutive years and short time spans (pers. comm. with Research Statistician E. Reinhardt, USDA Forest Service Intermountain Research Station, Missoula MT). This tally was conducted for all 3 of the following categories: 1) number of per annum observations between 1500 and 1940, 2) per annum observations expressed as a percent of the total fire records in database, and 3) per annum observations expressed as a percent of data recorded to date (Kilgore and Taylor 1979). 13

The frequency analysis also was conducted for fire years by fire severity type (Heinselman 1978, Kilgore 1978, Arno 1980, Kilgore 1985, Barrett et al. 1991, Agee 1993, Agee 1994, Heyerdahl et al. 1994, Brown [in prep], Morgan et al. [in prep.]). However, only 2 severity classes were used in this analysis, 1) "nonlethal", for forest types experiencing primarily nonlethal fires, and 2) "lethal", which includes data from stand replacement- and mixed severity fire regimes. A more refined breakdown was infeasible because the fire year locations often are vague with respect to forest cover type, moreover, some cover types have more than one characteristic fire regime (e.g. lodgepole pine). First, predominant severity patterns for each SAF forest cover type were determined by consulting written summaries (Arno 1980, Agee 1994) in tandem with the author's personal experience. Then the database fire years were assigned to their respective fire severity groups based on the associated primary SAF types. This analysis produces a small amount of "noise", because some area fire chronologies include data from both fire severity groups. Selection of a predominant severity type occasionally was difficult, but usually not for fire atlases and early written accounts because they typically document large, and primarily lethal, fires.

Another important goal was to examine the possible level of synchronization between coarse-scale fire frequency and trends in macroclimatic precipitation. Results of the fire frequency analysis (running 5-yr means of fire freq.) were graphed relative to ~~interpreted~~ drought episodes ~~that occurred~~ between ca.1500 and 1940 as identified from dendro. The method was to plot the smoothed results from tree ring series depicting long-term precipitation trends (Keen 1937, Graumlich 1987), as was done with the fire frequency analysis. Because smoothed results were used, "drought episodes" here refer only to periods of generally lower than average precipitation, as opposed to periods of absolute drought.

Characterizing macroclimatic precipitation for the entire greater CRB is difficult, given its large size and varying climatic influences. First, results from tree ring studies do not always agree precisely with modern precipitation records for a given area (Meko et al. 1993, Karl and Koscielny 1982). And second, the study area contains at least 2 partially overlapping drought regions, as indicated by the Palmer Drought Severity Index for the post-1895 period (Karl and Koscielny 1982) and tree rings dating from the 13th century (Keen 1937, Graumlich 1987, Meko et al. 1993). For example, droughts in the western- and eastern portions of the greater CRB often exhibit pattern differences. But because the study area is influenced primarily by a Pacific Maritime climatic regime, and by northeasterly summer jet streams, results from extensive tree ring sampling in eastern Oregon, eastern Washington, and northeastern California (Keen 1937, Graumlich 1987) are the most applicable for this study (pers. comm. with T. Swetnam and D. Meko, Laboratory of Tree Ring Research, Tucson AZ).

Fire Period Mapping. After important fire periods in the database were identified, the geographic locations of the fires was documented by mapping with a Geographic Information System (GIS). A base map (on file, USDA Forest Service Intermountain Fire Sciences Laboratory, Missoula MT) was used to plot results from the running 5-yr tally for all fire locations during apparently peak fire periods (i.e., fire year $\pm$ 2). To assess the possible geographic scope of these fires, all potentially recording sites (Kilgore and Taylor 1979) also were mapped for each fire period, that is, all unburned sites that had previously recorded fires.

RESULTS AND DISCUSSION

Database Attributes. The database contains 4360 fire records and other site information from 122 sources (i.e., fire history studies, fire atlases, written accounts)--totalling 321 sites with discrete latitudinal and longitudinal coordinates for GIS mapping. Most data were from 108 fire history studies postdating the mid-1970s, and about a third of these studies have been published. This database includes virtually every formal and informal fire history study completed as of April 1995 east of the Cascade Crest. The studies range from intensive, multi-year efforts in large sample areas (e.g. Glacier- and Yellowstone National Parks) to very informal assessments based on a single fire scarred tree. Because of legal concerns, numerous unpublished fire year data from northern spotted owl (*Strix occidentalis*) potential nesting sites in west-central Washington were not available for review. This information would have contributed substantially to the database, both in terms of quantity and geography. In addition to those from fire history studies, numerous (N=737) fires were plotted from ca. 1910 to 1940 fire atlases, largely from the Northern Rockies subregion. And finally, a few early-day accounts provided data on noteworthy forest fires, for example, in 1889 (Idaho Daily Statesman 1889).

The distribution of studies and fire records is highly skewed, both geographically and by author. For example, most (82%) of the studies were in the Northern Rockies, followed by the east Cascades (15%), and Blue Mountains (2%). Montana contained one-third of all studies, about 60 percent of which were on the west side of the Continental Divide. About one-quarter of the studies were in Idaho, and nearly 90 percent of these were in the central to northern portions. (Studies in the Northern Rockies by this author and by collegue S. F. Arno [Research Forester, USDA Forest Service Intermountain Research Station, Missoula, MT] together

comprise about a third of all data sources, and nearly 40 percent of the *bona fide* fire history studies. More importantly, work by these 2 authors produced nearly 45 percent of all fire records in the database. Theoretically, such a disproportionate contribution of data by 2 fire history specialists would yield greater overall accuracy than if the data had been equally distributed among all 58 study authors. [Further, nearly two-thirds of all fire records originated from the above 2 authors plus highly precise fire atlases]). The percentage breakdown by study location was roughly similar for the following states and provinces, ranging from 7 to 9 percent: Washington, Oregon, and peripheral areas (i.e., combined data from Alberta, British Columbia, northeastern California). And, as a separate entity, the Greater Yellowstone Ecosystem contained 9 percent of the studies.

Each state's and subregion's contribution to the total number of fire records (fig. 1) is roughly proportional to that enumerated above for the data sources. The sole exception is Montana, which yielded 34 percent of all data sources but nearly half of all fire records (fig. 2). Besides having good coverage by pre-1940 fire atlases, Montana clearly has received more thorough fire history sampling than any other area of the greater CRB.

About three-quarters of the fire records were obtained from fire scars, 17 percent were from written records (primarily fire atlases), and 10 percent were derived from analysis of post-fire seral age classes (fig. 3). The distribution of fire years by primary SAF forest cover type is also highly skewed (fig. 4). Data were derived for 17 cover types but 6 types provided most of the data: ponderosa pine, lodgepole pine (*Pinus contorta*), Interior Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), whitebark pine (*Pinus albicaulis*), and western redcedar (*Thuja plicata*)-western hemlock (*Tsuga heterophylla*). However, about 90 percent of

all fire records were from the following 3 cover types: ponderosa pine (45%), lodgepole pine (28%), and Interior Douglas-fir (15%).

The above breakdowns are highly disproportionate in comparison with each forest type's coverage of CRB forested land (Morgan et al. [in prep.]). For example, whereas studies in ponderosa pine produced nearly half of all fire years in the database, this cover type occupies only about 20 percent of the coniferous-forested land. Conversely, the grand fir- and spruce-fir cover types together comprise about 20 percent of the coniferous forest, but together produced less than 2 percent of the fire records. This partly reflects a traditional bias toward studying commercially valuable tree species, but also the fact that forests in the nonlethal fire regime typically yield large quantities of fire scar data per site. (The above results contain some "noise" because the data were organized according to primary [i.e., predominant] forest type--and some master fire chronologies include data from a diversity of types. Similarly, because primary cover type formed the basis for estimating a primary fire severity type in each study area, this caveat applies to the fire severity analysis below).

Only 3 of the 17 sampled cover types in the database (including one custom-defined class of Douglas-fir dominated stands [below]) were considered to belong to the nonlethal fire severity group (tables 1, 2). This group occupies about 25 percent of the coniferous-forested land in the greater CRB (Morgan et al. [in prep.]), but yielded more than half (56%) of all fire records in the database (fig. 5, table 1). Most (81%) of these data were from ponderosa pine stands, but the nonlethal group also includes data from Douglas-fir- or western juniper (*Juniperus occidentalis*) dominated stands at lower timberline. Western junipers are often readily killed by fire, but this cover type exists in an environment that was characterized by

relatively high fire frequency during presettlement times. Therefore, these few pieces of data were included in the nonlethal fire group, to help depict the relationship between nonlethal fire frequency and trends in macroclimate precipitation. The 14 remaining forest cover types in the database occupy about 75 percent of the coniferous-forested land in the greater CRB (Morgan et al. [in prep]), and these were assigned to the lethal severity group (i.e., data from stand replacement- and mixed severity fire regimes). This group provided 44 percent of the fire records (fig. 5, table 2). More sites were required for this amount of data because lethal fires are substantially less frequent than nonlethal fires, and lethal fires destroy more evidence of long-term fire history. Consequently, the distribution of data from lethal- and nonlethal regimes is highly skewed in time. Before about 1910, for example, the nonlethal group comprised nearly two-thirds of all fire records. Conversely, the lethal group comprised nearly three-quarters of all fire records between 1910 and 1940. The latter skewed distribution is caused both by numerous fire atlas data, which document primarily lethal fires, and by increasingly effective fire exclusion in the nonlethal fire regime (discussed below).

Fire Frequency. In addition to the 4360 fire records for ca.1500 to 1940, a few data (N=15 records) were obtained for ca.1200 to 1500. Relatively continuous data began by ca.1500, but even so, there were only 127 fire records for the entire 16th century (figs.6, 7). The 321 study sites thus yielded an average of 14 fire records each between 1500 and 1940. (Each "study" provided an average of 33 fire records each). A mean of 10 fires occurred each year in this sampled portion of the greater CRB, or, an average of one out of every 30 sample sites burned annually during the last 4 centuries.

Regarding the possible cumulative effect of various estimation errors on this study's outcome, an informal attempt was made to estimate overall accuracy. The following conservative assumptions were used. First, only 30 percent of the fire year estimates from fire scars were likely to be correct; second, only 10 percent of the estimates from post-fire seral regeneration were accurate, and third, all written records were accurate. When these percentages are multiplied by the data sources' respective proportions of the total database (73%, 10%, 17%, respectively), then summed, an overall accuracy level of 40 percent results. However, database accuracy would be highly skewed between the pre- and post-1900 periods (i.e., pre-fire atlas period). Estimated accuracy between ca.1500 and 1900 would be less than 30 percent because the data are largely from fire scars and post-fire regeneration. However, database accuracy after 1900 would increase to 72 percent because of the numerous fire atlas data. In summary, based on conservative estimates, overall accuracy for database fire years may have been as low as 25 percent for most of the analysis period (1500-1900), followed by a possibly threefold increase in accuracy after ca.1900.

The preceeding discussion refers only to the percentage of time that fire year estimates were likely to be correct. It is not possible to identify which database fire records are incorrect, nor to estimate an average range of error (e.g., standard deviation). With the running 5-year tally, however, annual fire frequency (i.e., year $\pm$ 2) was expressed as a percent of total data to date (Kilgore and Taylor 1979) as a measure the relative importance of any given 5 year period. Because of the many uncontrollable variables, and the skewed distribution of data over time, directly comparing fire frequency between early- and later periods in the chronology is infeasible (pers. comm. with Research Statistician E. Reinhardt, USDA Forest Service Intermountain

Research Station, Missoula MT). But, indirect comparisons may be possible by examining fire frequency relative to precipitation patterns, which are more accurate than the fire data.

Three fire frequency graphs were produced (fig. 8): nonlethal, lethal, and overall frequency (the latter is the sum of results from the 2 severity groups). When the running 5-year tally was initiated for ca.1500, statistically meaningful results began to appear by the mid-1500s. That is, only one percent of the fire records pre-date 1540 (N=41 records), so data for any given year before 1540 represent a disproportionately high percentage of the total data to date. The fire frequency curve subsequently grew more stabile, but data sparsity before ca.1600 still caused some exaggerated peaks and troughs. Nonetheless, fire frequency trends across the entire 400-year span of data appeared to be closely synchronous with trends in macroclimatic precipitation. Major peaks and troughs on the graphs usually occurred within 5 years of pronounced drought- or mesic periods (Keen 1937, Graumlich 1987), suggesting a virtually direct relationship between the 2 phenomena.

The 400 year fire chronology revealed the following general patterns of apparent synchronization between fire frequency and macroclimatic precipitation. Approximately 24 pronounced droughts occurred between 1540 and 1940, that is, general periods of substantially below average precipitation (Keen 1937, Graumlich 1987). These episodes spanned from one- to as many as 23 years long, but averaged about 8 years long--and nearly half of the years between ca.1500 and 1940 experienced drought. The fire history data reveal that at least 32 peaks in fire frequency had closely coincided with these 24 drought episodes (fig. 8). Droughts and concurrent peaks in fire frequency therefore averaged about every 13 to 17 years. The graphs depict only a few instances of seemingly non-synchronous fire- and precipitation trends.

Estimation errrors likely caused this result because the graphs usually show major droughts within a few years of the non-synchronous peaks in fire frequency (e.g., see ca.1703 to 1708, 1725 to 1730 periods). The coarse scale data thus suggest that there were no major fire periods without major drought. Conversely, the graphs depict a number of prominent troughs in fire frequency during mesic periods, or, generally flatter graph segments (fig. 8).

Following is a more detailed analysis of the apparent level of synchronization between coarse-scale fire history and macroclimatic precipitation since 1540. Keen (1937) suggests that a number of severe droughts occurred during the 1500s, and as many as 6 occurred between 1540 and the mid-1600s (fig. 8). Sparse fire data in the pre-1650 portion of the chronology contributed to erratic graph behavior, but inversely related trends in fire frequency and precipitation are still readily apparent (figs. 6, 7). Drought duration declined substantially during the cool-mesic Little Ice Age, between ca.1650 and 1850, and the fire frequency curves are generally flatter during this period. Nevertheless, 8 of the 20 most severe individual drought years in the CRB between 1675 and 1975 occurred during the early to mid-1700s (Graumlich 1987). Several prominent peaks in the fire frequency occurred during that time. Subsequently, a pronounced peak in fire frequency occurred in ca.1802, closely coinciding with a major drought between ca.1793 and 1800. Droughts and fires were infrequent during the next 4 decades, followed by pronounced drought between ca.1839 and 1852, at the end of the Little Ice Age. The lethal- and nonlethal fire frequency curves for this approximately 13 year span depict roughly parallel trends that are offset by several years, thus reducing the curve for overall frequency. However, there was at least one prominent fire year, perhaps in 1839--the 4th most severe drought year in the Columbia River Basin between 1675 and 1975 (Graumlich 1987).

Between the late 1800s and early 1900s, fire frequency grew highly erratic in response to recurrent droughts of increasing severity and duration. The graphs show major peaks in fire frequency in ca.1870, ca.1887, ca.1913, and ca.1919, largely reflecting data from the region's most notorious fire years in 1889, 1910, 1919 (Larsen and Delaven 1922, Pyne 1982)(fig. 9). The latter 3 peaks in fire frequency appear substantially out of scale when compared to previous periods in the fire chronology (except for the pre-1600 period, when scarce data exaggerated the annual frequencies). The fire location maps (fig. 10) also illustrate the importance of these 3 fire years, but the fires in ca.1889 and 1919 evidently were even more widespread than in 1910. Remarkably, a number of study sites under the lethal severity group burned during all 3 of the above years (Larsen and Delaven 1922, Gisborne 1932, Barrett 1982, Zack and Morgan 1994), and these triple burns often produced persistent seral shrubfields on previously forested terrain (Larsen 1924, Larsen 1929, Barrett 1982). Some prehistoric fire years, such as during the early to mid 1700s, might well have been comparable to those after 1888. The imprecise data preclude a more definitive interpretation but, based on the fire history- and climate data to date, the post-1888 fires probably were not unprecedented.

The holocaustic 1910 fires (Koch [undated]) often serve as an archetype of worst case fire scenarios in the West. And public outrage in the aftermath may have spurred the *de facto* birth of the USDA Forest Service as an effective land management agency (Pyne 1982). Still, the database contained 16 percent fewer fire records for 1910 than 1889, despite the fact that there were 10 percent more potentially recording sites in 1910. The 1889 fires evidently were more widespread, but the 1910 fires were highly unique. First, in an area extending from north Idaho to northwest Montana, high winds enabled the 1910 fires to burn an estimated 3 million

acres of forest in just 3 days, largely in heavy fuels (i.e., lethal severity group)(Koch [undated]). The 1910 fires also killed 85 people and destroyed several settlements in narrow mountain canyons. By comparison, the fire history samples and written accounts (Idaho Daily Statesman 1889) suggest that the 1889 fires had burned in a wide array of forest types over a more normal burning period. The 1889 fires thus may have been less threatening than those in 1910, especially given the fact that European settlements were less extensive. Early-day attitudes about fire, and less effective media communications, also might help explain why the 1889 fires lack notoriety. Newspapers (Idaho Daily Statesman 1889) indicate that the 1889 fires certainly were troublesome, but also imply that wildfires were still relatively commonplace in the mountains. This is borne out by the fire- and precipitation data (fig. 8), as well as the fire location maps (fig. 10), all of which suggest increasingly frequent droughts and widespread fires after the mid-1800s.

Some of the worst drought in the Pacific Northwest during the last 3 to 7 centuries occurred between 1917 and 1941 (Keen 1937, Laephart and Stage 1971, Graumlich 1987, Karl and Koscielny 1982). Recurrent severe fire seasons, at least on a subregional basis (fig. 10), occurred in 1919, 1929, 1926, 1934, 1936, 1917, and 1931, and averaged every 3 years during the 24-year period. This extreme level of fire activity may have been unprecedented during the 4-century span of data. Yet, paradoxically, lethal- and overall fire frequency declined steeply in the early 1930s (fig. 8). In fact, the curve for nonlethal fire frequency grew distinctly flatter after ca.1900, when only a few relatively small peaks occurred even during the most pronounced drought years (fig. 8). These trends presumably reflect increasingly effective fire exclusion in the Inland Northwest, starting with dry lower elevation stands near habitation zones (i.e.,

nonlethal severity group). (Also note that the large discrepancy between lethal- versus nonlethal fire occurrence after 1910 is partly a result of numerous data from fire atlases, which document primarily lethal fires and total 17 percent of the database). Post-1940 data were not entered during the literature review. Based on informal observation of the results from numerous studies, however, fire frequency during the remainder of the fire suppression era would often approach zero on the Y-axis, except for a few noteworthy years (e.g., 1967, 1979, 1984, 1988, 1994). In hindsight, results from this study would have been made even more meaningful had such data been collected. Such information would have enabled a more thorough interpretation of fire suppression's effectiveness by fire severity group at the coarse scale.

The potentially direct relationship between macroclimatic drought and regional fire history is perhaps best demonstrated by the results for the post-1880 period. Still, peaks in drought and fire frequency were not always synchronous, conversely, severe fire years sometimes occurred in the absence of drought. Whereas 1889 represents the most severe drought ever recorded in the Pacific Northwest (Karl and Koscielny 1982, Graumlich 1987), neither 1910 nor 1919 rank among the top 20 worst drought years (Graumlich 1987). Similarly, 1922 was the 5th most severe drought year in the CRB between ca.1675 and 1975 (Graumlich 1987), but the database does not reveal widespread fires during that time. In general, however, data for the well documented post-1888 period clearly indicate that fire activity usually increased during or immediately after periods of intense drought.

Drought and fires likely were highly synchronous during the prehistoric era as well (fig. 8). The known post-1888 patterns may provide insight into the possible level of database accuracy. Most peaks and troughs in overall fire frequency occurred within 5 years of

apparently corresponding (i.e., inversely related) trends in precipitation. For instance, a major drought between ca.1591 and 1601 may have peaked by ca.1594 (Keen 1937), whereas the graph of overall fire frequency suggests peaks in ca.1594 and 1602 (fig. 8). (That is, the nonlethal graph suggests peaks in ca.1594 and 1603; the lethal graph suggests peaks in ca.1593 and 1602). Furthermore, all 3 graphs depict marked reductions in fire frequency during the late 1590s, when precipitation apparently had recovered briefly in ca.1597. Similar oscillations occurred during droughts between ca.1562 and 1585, ca.1645 and 1647, and other periods. For the known period, the severe drought between ca.1882 and 1891 had peaked in 1889 (Graumlich 1987, Keen 1937, Laephart and Stage 1971). The curve for overall fire frequency suggested maximum activity between ca.1887 and 1891, reflecting the numerous data for the 1889 fire year and the averaging effect of the running 5-year tally. In view of the fact that peaks in drought and fire frequency do not always coincide, and because the frequency analysis was for ± 2 years from any given year, most estimates from the original studies probably were within about 5 years of an actual site fire year. This surprisingly high level of accuracy was unexpected, given the large size of the database, the wide array of data sources, and the preponderance of uncrossdated analyses-- which often become increasingly error prone with receding time (Madany et al. 1983). In fact, the results suggest that database accuracy may have been relatively constant. (Numerous precise data from fire atlases had little appreciable affect on overall accuracy because these data spanned less than 10 percent of the chronology). Any imprecision caused by sparse data and few studies early in the chronology conceivably could be comparable to that during later periods, when large numbers of data from many studies generated more errors.

When frequency was analyzed by fire severity group (fig. 8), the graphs were somewhat

more erratic with respect to macroclimatic precipitation and to one another. For example, prominent peaks and troughs occasionally appear to coincide between the 2 fire severity groups. Otherwise, trends are often parallel but offset by several years on the X-axis. These errors might suggest inherently different estimation accuracy, and skewed data, among the 2 groups. Similar amounts of data were obtained from the nonlethal- and lethal severity groups (i.e., 56% vs. 44%, respectively). However, the nonlethal fire records were nearly twice as numerous as those for the lethal group for nearly 95 percent of the chronology (i.e., pre-1910 era). Because the nonlethal group produces substantially more data per site than the lethal group, the latter required more study sites, and possibly a greater number of studies, in order to acheive a like amount of data. Furthermore, the lethal group contains most of the precise fire atlas records (80% of the group's post-1900 records), yet most of the relatively inaccurate records from post-fire seral regeneration alone (30% of the group's pre-1900 records). Virtually all of the nonlethal fire records were from fire scars, which may provide more constancy in the results. These complex interacting variables make it virtually impossible to predict a cumulative effect on estimation accuracy, but such factors occasionally produced anomalous fire frequency trends.

The 2 fire frequency curves generally were parallel, but the nonlethal curve occasionally was less erratic than the lethal curve. Several factors, such as the relative number of fire records per group, the total number of records in each group for any given year, and the possibly inherently different accuracy levels per group, might contribute to this pattern. However, other factors might contribute to making the nonlethal fire regime less sensitive to trends in macroclimatic precipitation. Ponderosa pine stands with light understory fuels remain highly combustible throughout much of each fire season, so fire occurrence may have been less

dependent on macroclimatic drought. As well, Indians burned many valley bottom stands virtually annually, thereby reducing the level of amount of variation in fire frequency that would have occurred from lightning fires alone. By comparison, the lethal curve sometimes depicts more prominent peaks and troughs that are inversely related to trends in macroclimatic precipitation. Despite substantially fewer pre-1900 fire records, lethal frequency often surpassed that for nonlethal fires during severe droughts. These patterns suggest that lethal regimes are substantially more responsive to major shifts in macroclimatic precipitation, and lethal fires may be largely dependant on recurring drought. But the actual degree of response to shifting macroclimatic precipitation undoubtedly varies somewhat from that depicted on the graph. The fire frequency curves are only rough approximations, both chronologically and in terms of severity grouping. Both groups unavoidably contain a few data from fires of the opposing severity type and, furthermore, the lethal fire group is composed of data from the stand replacement- and mixed severity fire regimes. Mixed severity fires are likely less dependent on drought than stand replacing fires, and this may reduce the apparent level of sensitivity between "lethal" fire frequency and macroclimatic precipitation.

Geographic Distribution of Fires. The database was searched for any site "major fire years" coinciding with the 34 peak fire- and drought periods, to help determine the relationship between peak fire occurrence at the coarse scale and important fire years in the individual study areas. The database contains 704 site major years, but these data are somewhat limited in scope because less than 25 percent of the 321 study areas were sufficiently large to produce such information. Nearly 80 percent of the site major years were in the lethal fire severity group, and

20 percent were in the primarily nonlethal fire group. A tally of these major years by decade suggested close agreement with fire frequency peaks at the coarse scale about 60 percent of the time. Therefore, in light of their limited number and scope, these data were not very useful for mapping. Still, these results reveal that important fires often occurred at the site- or subregional scale when other areas in the greater CRB apparently lacked substantial fire activity (e.g. in 1910). The data also help illustrate the size potential of lethal fires: these site major years comprised more than a third of all lethal fire records in the database.

A GIS was used to produce maps of fire locations during the 34 peak fire periods (1: 5 million scale; Appendix C). Specifically, the maps depict the locations of all fire years within $\pm$ 2 years of an apparently drought-induced peak in fire frequency at the coarse scale. Important fire periods also were interpreted by plotting any potentially recording sites during each period, that is, unburned sites with evidence of previous fires (Kilgore and Taylor 1979). The utility of the maps is somewhat limited by the fact that two-thirds of the pre-1910 data were in the non-lethal fire group. Inherently high fire frequency in such stands likely diminishes the ability of these maps to accurately portray the locations of important fire years because: 1) the nonlethal regime may be less responsive to macroclimatic drought, and 2) the master fire chronologies for such sites often contain one or more fires during any given 5 year period.

To help provide a geographic perspective of fire occurrence during worst-case drought scenarios, an analysis was conducted of the distribution of fire records by 4 subregions: Northern Rocky Mountains, Greater Yellowstone Ecosystem, Blue Mountains, East Cascades. Specifically, fire records were tallied for 10 important fire periods (i.e. yr $\pm$2), 9 of which had closely coincided with some of the most severe drought years since ca.1675 (Graumlich 1987).

To measure the relative importance of a given fire period geographically, results were expressed as a percentage of the total data to date in each subregion (table 3, fig. 10). Results suggest that fire frequency was highly variable among the 4 subregions, even during some of the worst droughts. Fire frequency was similar among all 4 subregions in only 2 or 3 instances: ca. 1756, ca.1797, and possibly 1736/39. By comparison, the ca.1889 fire period was important in all subregions except for the Greater Yellowstone Ecosystem; fires during ca. 1777 were widespread primarily in the East Cascades; and fires in ca.1737 apparently were most pronounced in the Greater Yellowstone Ecosystem. The historic 1910 fire year, which apparently was not among the 20 worst drought years between ca.1675 and 1975, was most pronounced in the Northern Rockies--largely in northern Idaho and northwestern Montana. Some of this variation might reflect differing macroclimatic patterns, for example, site fire histories east of the Continental Divide might have been influenced by the Continental- versus the Pacific Maritime climatic regime. Nonetheless, the results imply that fires during any given year during the past 4 centuries were only rarely very widespread, and that macroclimate is only one of the important influences on fire occurrence. Other variables, such as local weather, ignition sources, fuel types, terrain, and human habitation patterns, presumably play important roles in the fire history of any given locale.

In summary of overall results from this study, a compilation of 4360 fire records for the last 4 centuries in the greater CRB suggested that there is a potentially direct relationship between coarse-scale fire frequency and macroclimatic drought. The most recent period in the chronology, ca. 1889 to 1940, contained a number of very severe fire seasons, but also showed

evidence of effective fire exclusion in Inland Northwest forests. These findings yield potentially important interpretations for future forest management scenarios under shifting climatic regimes. For example, although major fire activity occurred on an average of about once every decade in the greater CRB, the actual range of intervals between important fire years was highly variable. Some relatively long periods (e.g., spanning several decades) occurred between consecutive severe fire years, whereas others were separated by as little as only one or 2 years. But wildfires during any given year were rarely very widespread throughout the entire region.

Results from these climate- and fire history studies might be useful for educating the public, as well as some politicians and forestry professionals. At the stand scale, such data can point to ecologically appropriate stand management prescriptions (Arno and Brown 1989, Mutch et al. 1993, Agee 1994). The information also can contribute in the policy arena by clarifying fire's role in pre-1900 ecosystems, thereby assisting in the formulation of management guidelines for long-term forest health (Mutch et al. 1993). For instance, fire regimes data can form one basis for decisions on whether and how to initiate "restoration forestry" in various western forest types. Otherwise, in the absence of innovative land management, major landscape change will continue to result largely from wildfires.

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Table 1. Distribution of fire records in the nonlethal fire severity group (percent of database in parentheses). *Codes*: PP (ponderosa pine), Int. DF (Interior Douglas-fir), WJ (western juniper).

SAF #	Type	# records
237	PP	1980 (45%)
999[a]	Int. DF	422 (10%)
238	WJ	55 (1%)
	SUBTOTAL:	**2457 (56%)**

Table 2. Distribution of fire records in the lethal fire severity group (i.e., mixed- and stand replacement regimes)(percent of database in parentheses). *Codes*: LPP (lodgepole pine), WL (western larch), WB (whitebark pine), RC (western redcedar), WH (western hemlock), Pac. DF (Pacific Douglas-fir), WP (white pine), RF (red fir), MH (mountain hemlock), S-F (Engelmann spruce-subalpine fir), GF (grand fir).

218	LPP	1197 (28%)
212	WL	226 (5%)
210	Int. DF	196 (5%)
208	WB	75 (2%)
227	RC-WH	66 (2%)
230	Pac. DF-WH	49 (1%)
215	WP	26 (<1%)
226	CF-WH	22 (<1%)
207	RF	18 (<1%)
205	MH	10 (<1%)
228	RC	8 (<1%)
206	S-F	5 (<1%)
224	WH	4 (<1%)
213	GF	1 (<1%)
	SUBTOTAL:	**1903 (44%)**

[a] This custom type (not an SAF type) refers to lower timberline stands dominated by Interior Douglas-fir stands.

Table 3. Distribution of fire data in 4 subregions according to 10 peak fire- and drought periods. Results from the running 5-year tally expressed as a percentage of data recorded to date within each subregion.

Codes:

N.Rockies: northern Rocky Mountains (western- to central Montana, central- to northern Idaho, Northeastern Washington,western Alberta, southeastern British Columbia);

G.Y.E.: Greater Yellowstone Ecosystem (northwestern Wyoming, eastern Idaho, and southwestern to south-central Montana);

B.Mts: Blue Mountains (northeastern Oregon, southeastern Washington);

E.Cascades: east slope of Cascade Mountains (Washington, Oregon, Northern California).

		No. Fire Records by Subregion[2]			
Fire Period	**Drought Yr: rank[3]**	**N.Rockies**	**G.Y.E.**	**B.Mts**	**E.Cascades**
1889 ± 2	1889: 1st	132/1959 (7%)	13/555 (2%)	9/131 (7%)	22/481 (5%)
1720 ± 2	1721: 2nd 1717: 6th	30/428 (7%)	9/148 (6%)	0/3 (N.A.)	3/85 (4%)
1758 ± 2	1756: 3rd	37/671 (6%)	14/226 (6%)	2/8 (N.A.)	7/123 (6%)
1842 ± 2	1839: 4th	62/1395 (4%)	15/422 (4%)	1/64 (2%)	20/345 (6%)
1920 ± 2	1922: 5th	173/2532 (7%)	7/612 (1%)	5/158 (3%)	13/562 (2%)
1929 ± 2	1929: 7th	110/2735 (4%)	8/626 (1%)	4/165 (2%)	12/587 (2%)
1737 ± 2	1739: 8th 1736:11th	29/523 (6%)	14/180 (8%)	0/3 (N.A.)	6/99 (6%)
1777 ± 2	1776: 9th	34/805 (4%)	14/271(5%)	3/13 (N.A.)	13/168 (8%)
1802 ± 2	1797: 14th	68/2879 (2%)	16/652 (3%)	4/168 (2%)	17/609 (3%)
1910 ± 2	N.A.	122/2246 (5%)	11/596 (2%)	4/151 (3%)	16/531 (3%)

[2]No. period records/no. records to date.

[3]Rank among 20 worst drought years between ca.1675 and 1975 (Graumlich 1987).

LIST OF FIGURES

FIG. 1. FIRE YEAR DATA BY SUBREGION
Ca.1500-1940 (N=4360 Records)

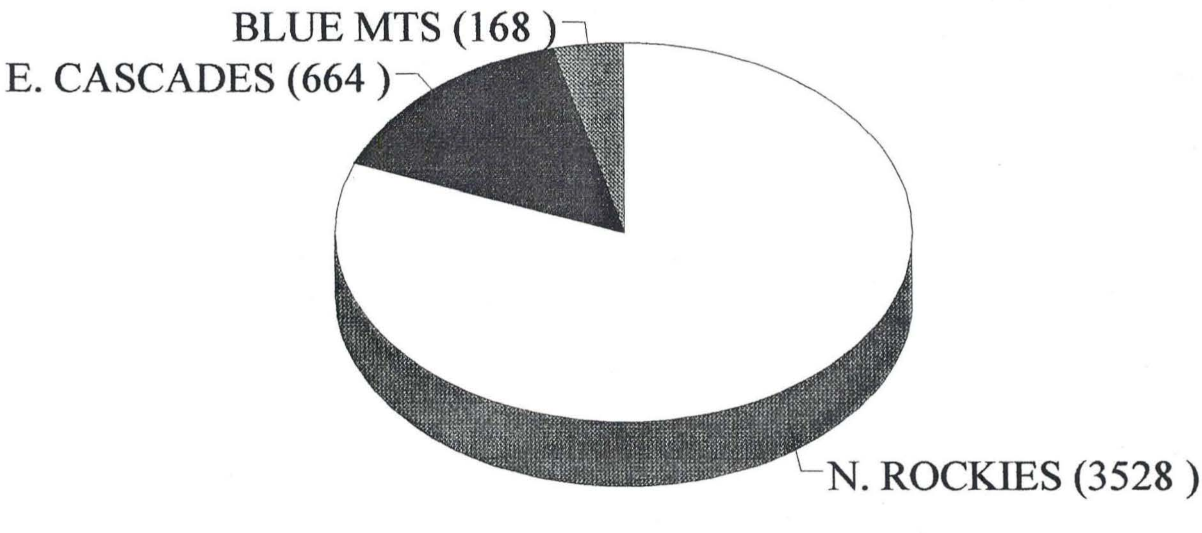


FIG. 2. FIRE YEAR DATA BY STATE/PROVINCE

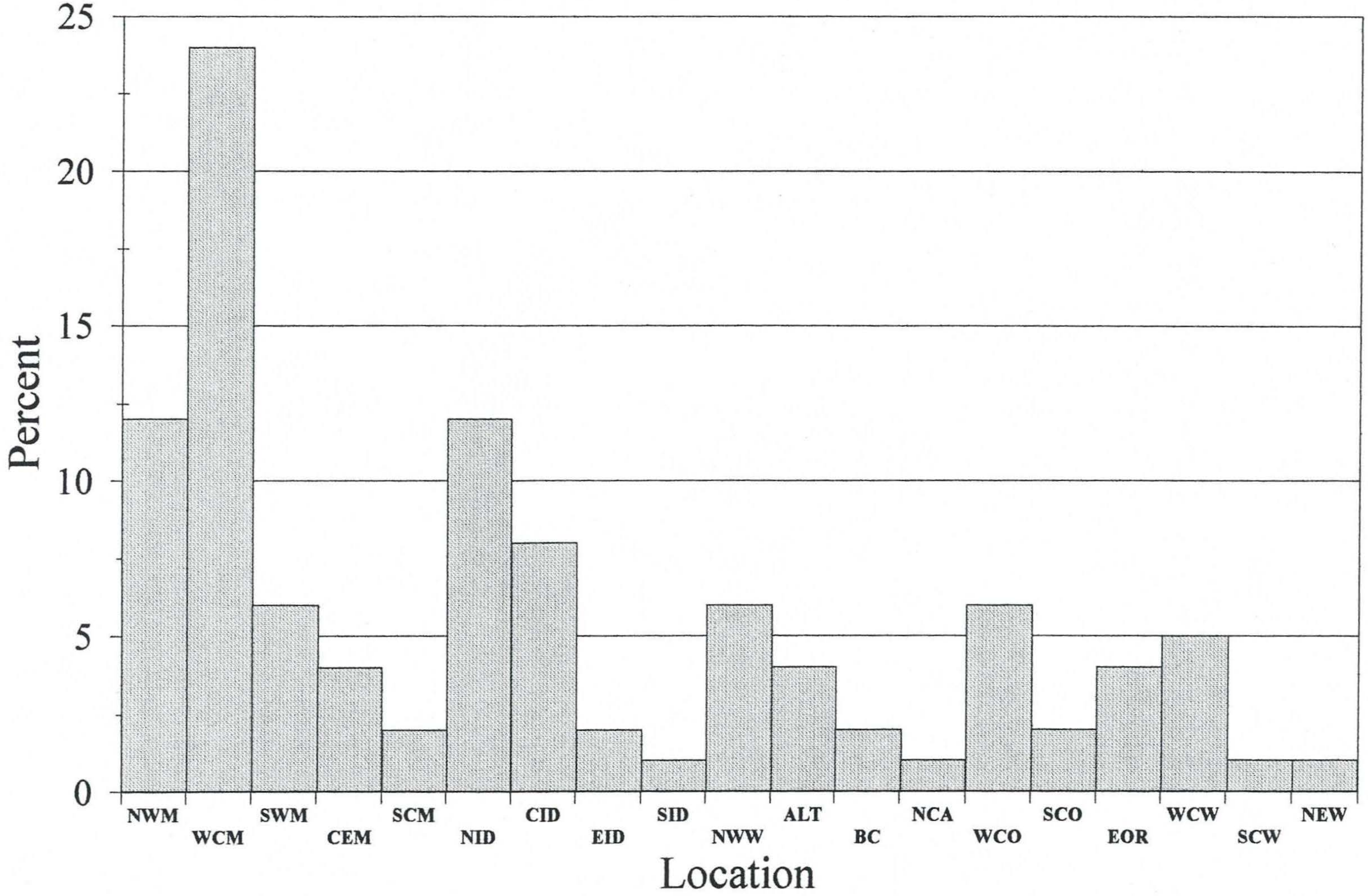


FIG. 3. FIRE YEAR DATA BY SOURCE

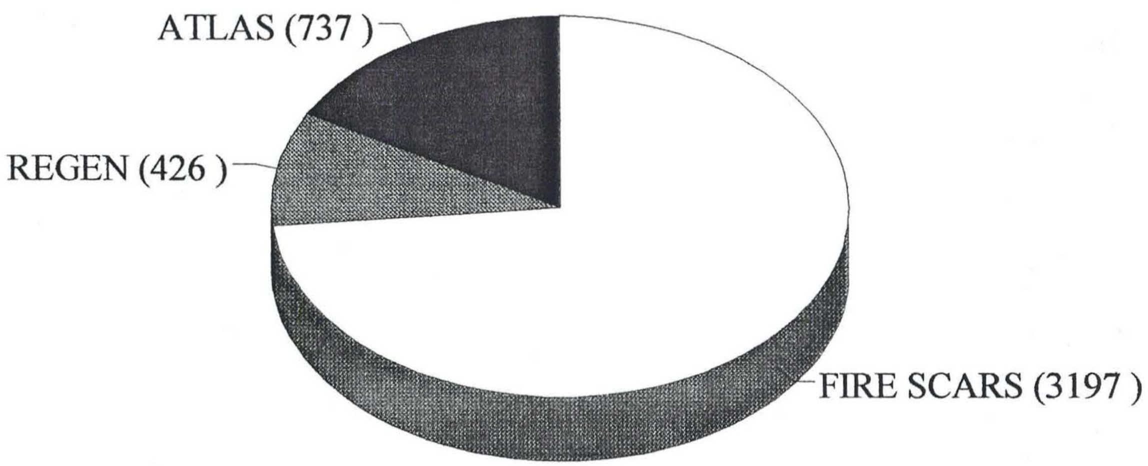


FIG. 4. FIRE YEAR RECORDS BY SAF TYPE
(N=4360)

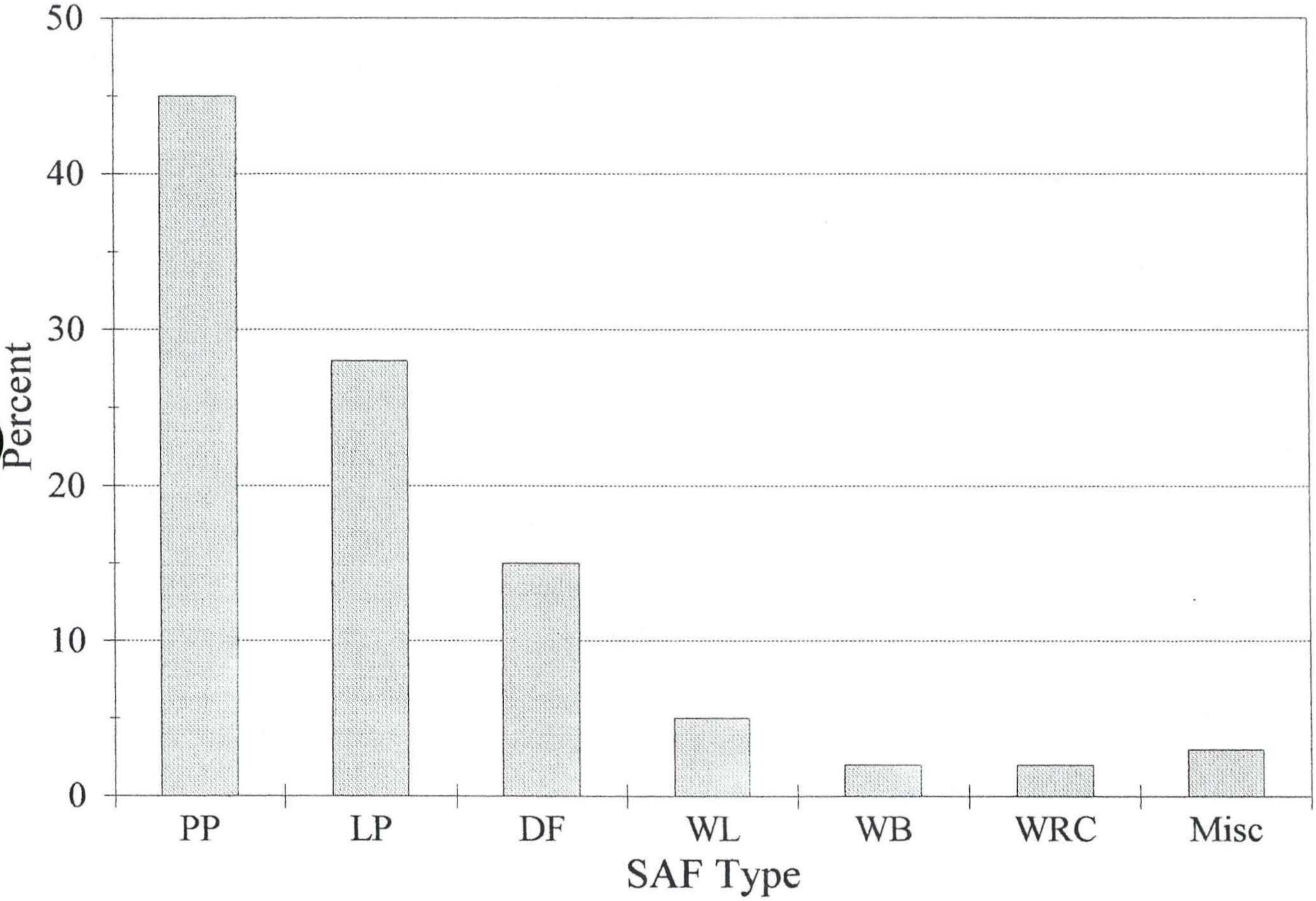
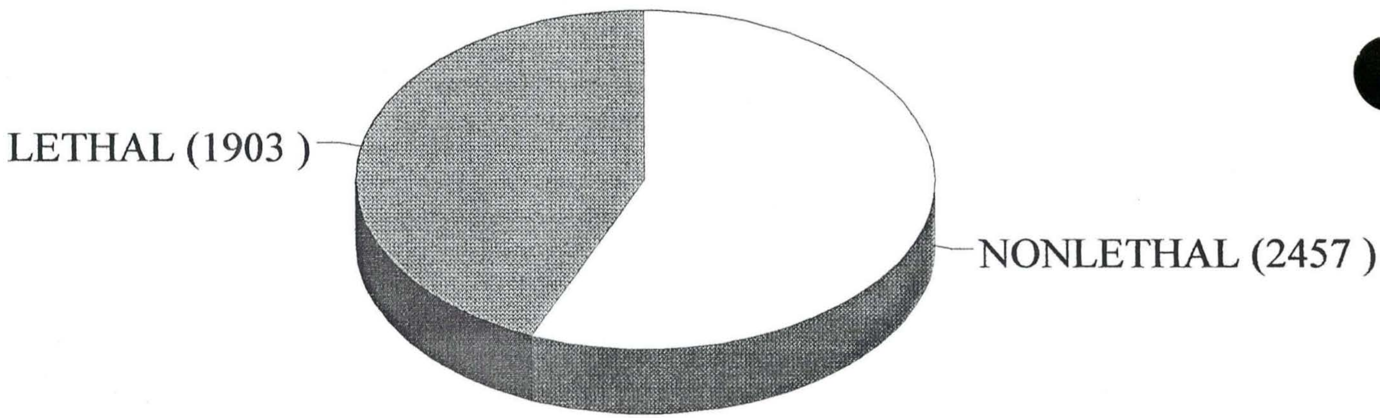


FIG. 5. FIRE YEAR DATA BY SEVERITY GROUP



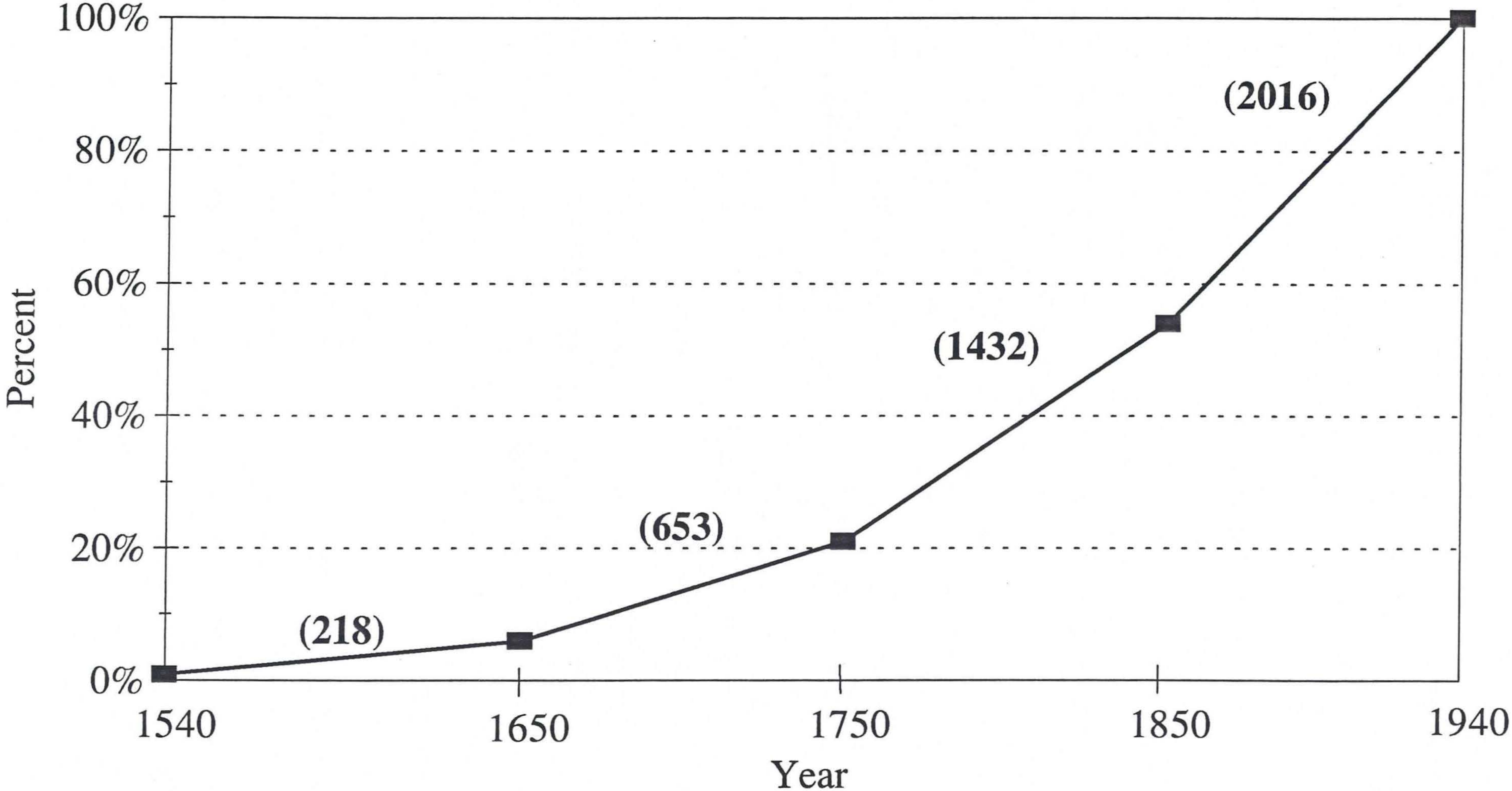
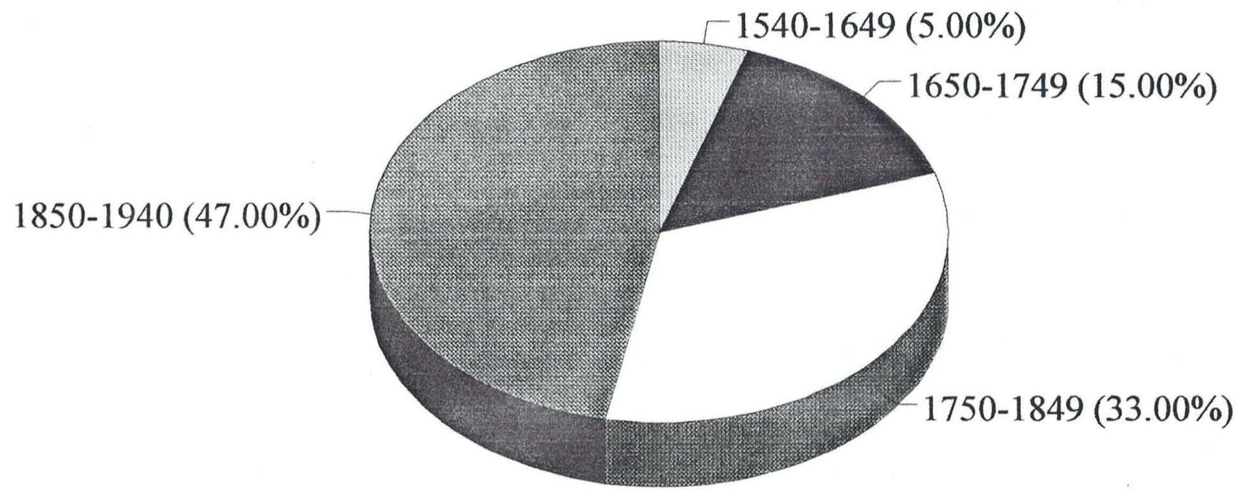

100%
80%
60%
40%
20%
0%
Percent
(218)
(653)
(1432)
(2016)
1540
1650
1750
1850
1940
Year

FIG. 7. FIRE YEAR DATA BY TIME PERIOD
Ca.1540-1940 A.D.



Overall Fire Frequency

1540 - 1940

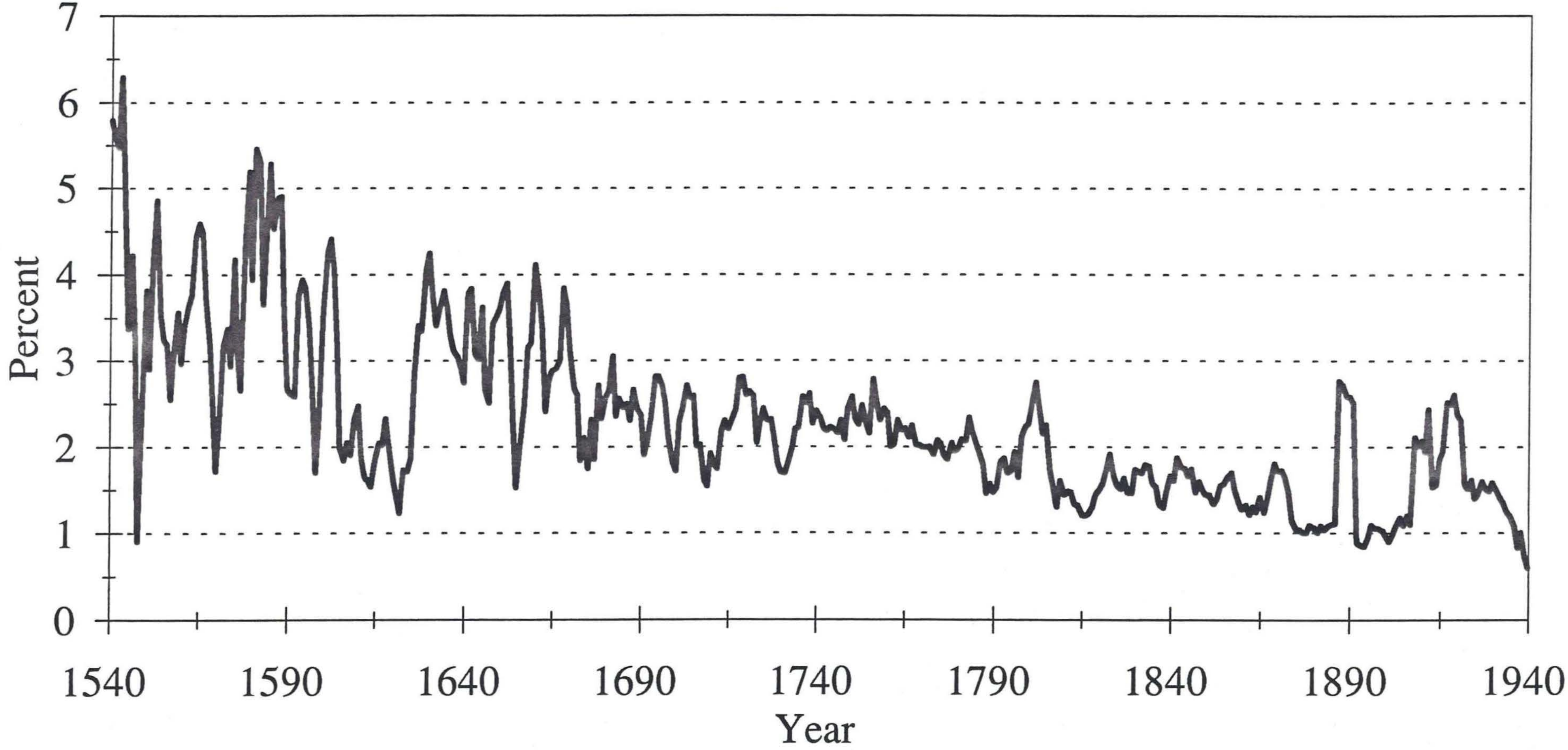
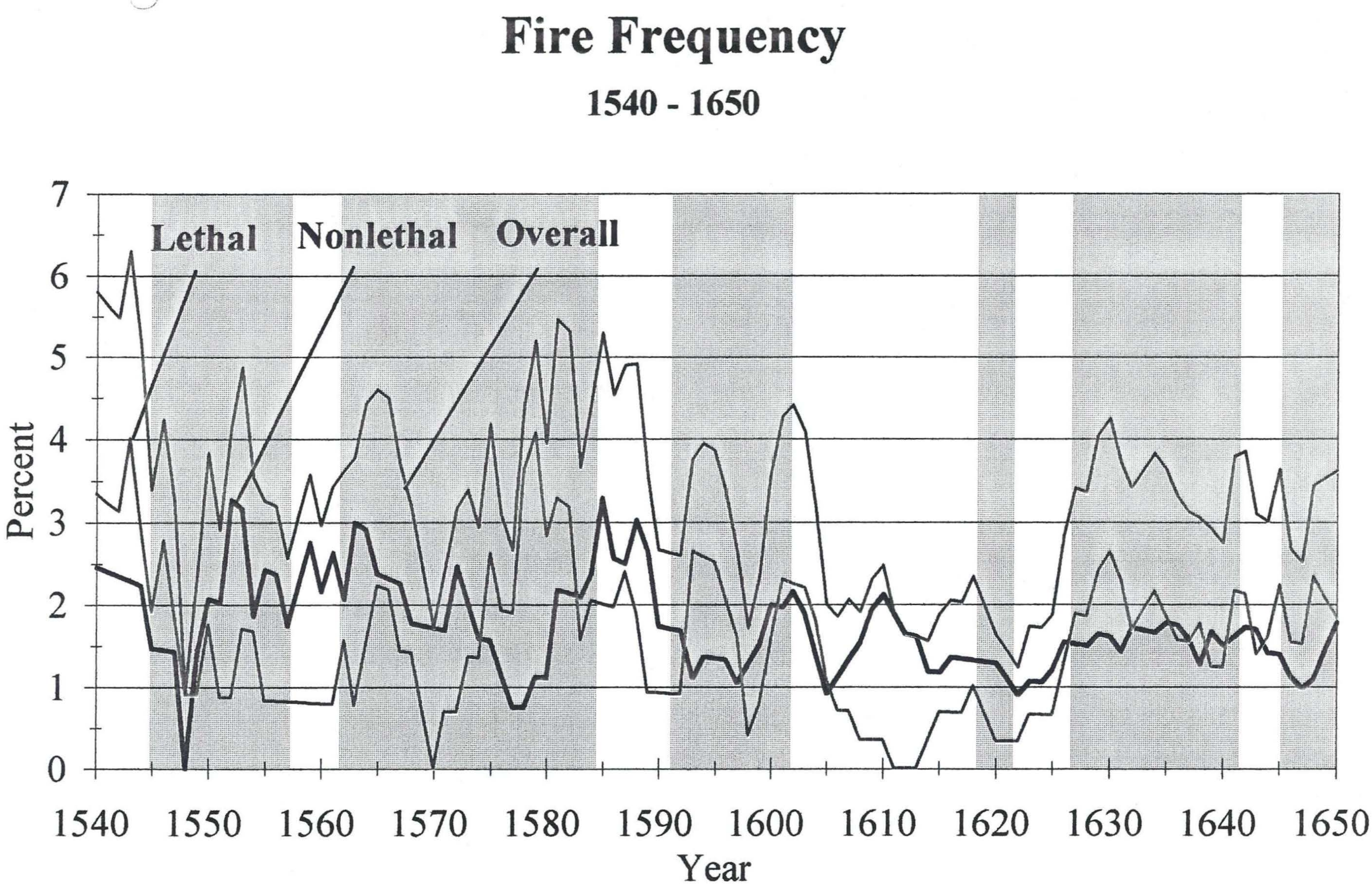


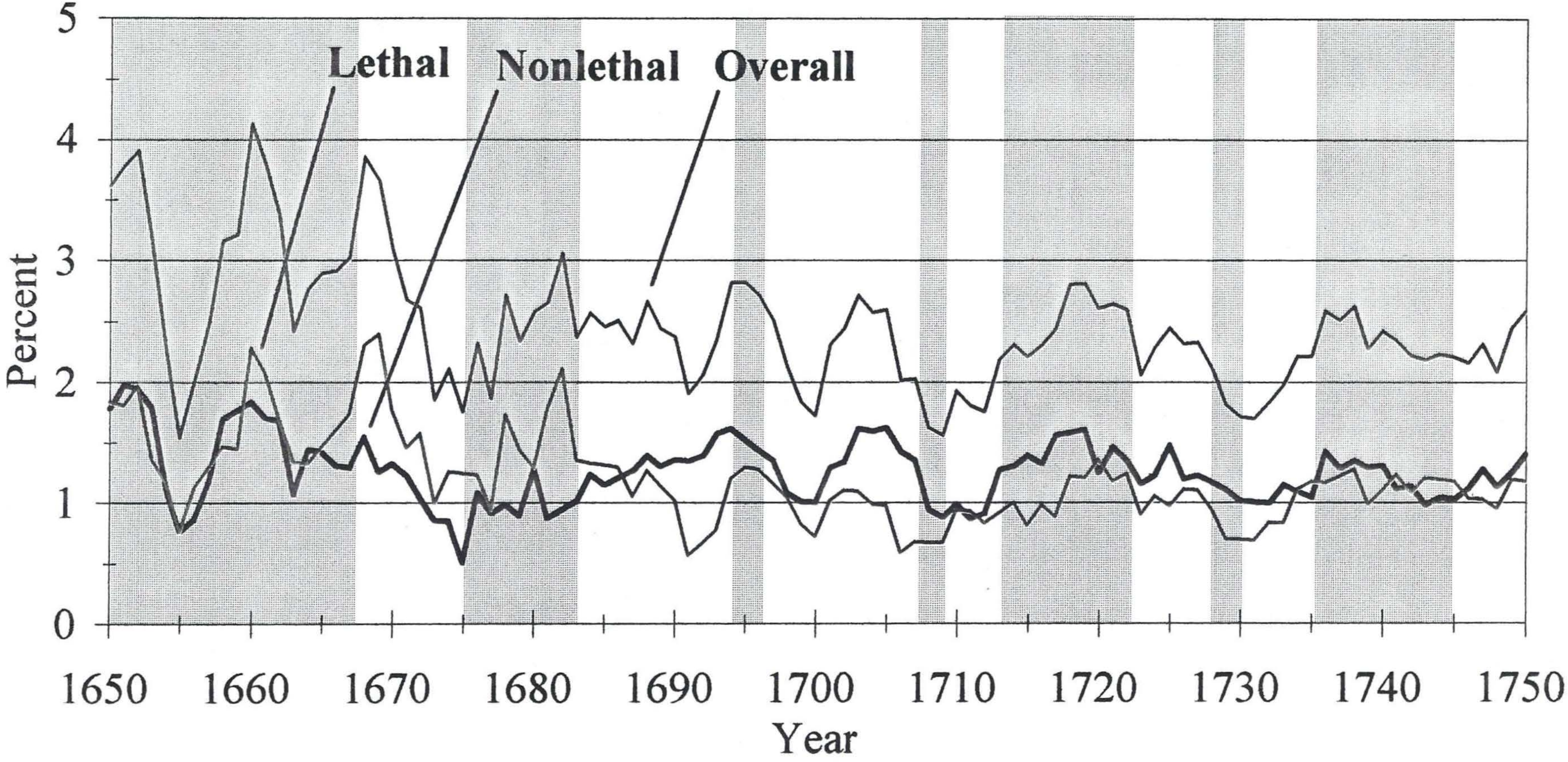
Fig 8



Fire Frequency
1540 - 1650
Lethal
Nonlethal
Overall
Percent
0
1
2
3
4
5
6
7
1540
1550
1560
1570
1580
1590
1600
1610
1620
1630
1640
1650
Year

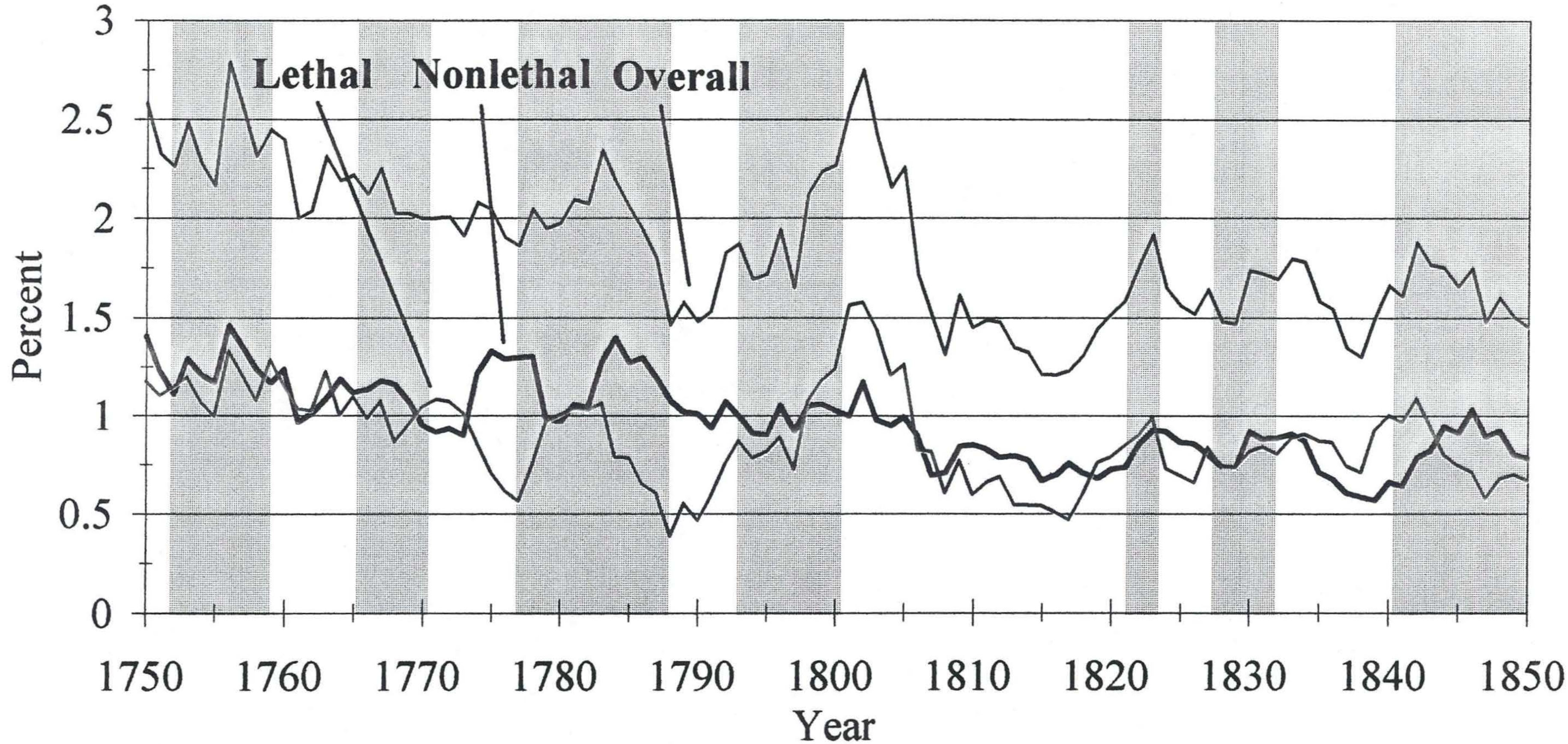
Fire Frequency

1650 - 1750



Fire Frequency

1750-1850



Fire Frequency

1850 - 1940

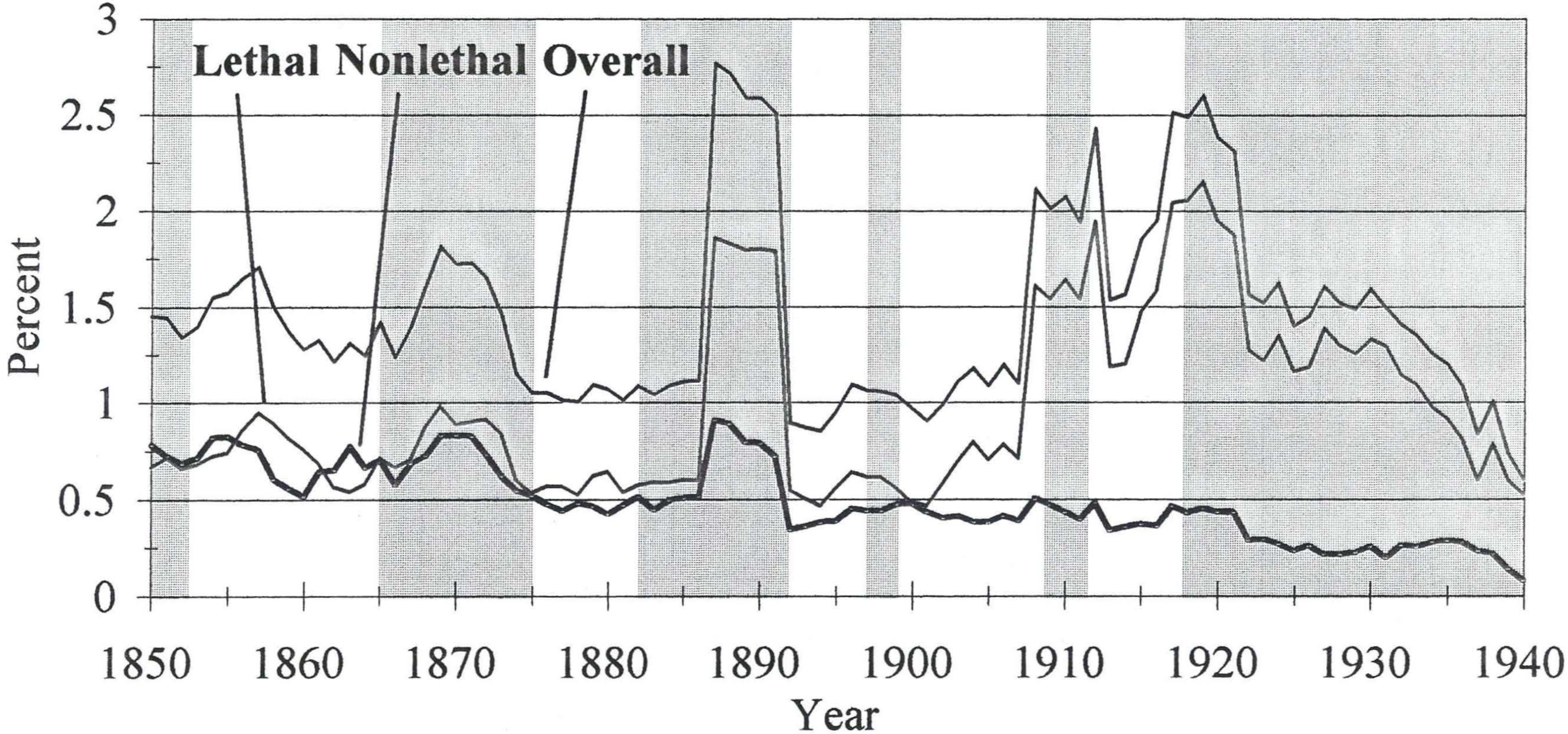


FIG. 9. RELATIVE FIRE FREQUENCY FOR 3 HISTORIC FIRE YEARS

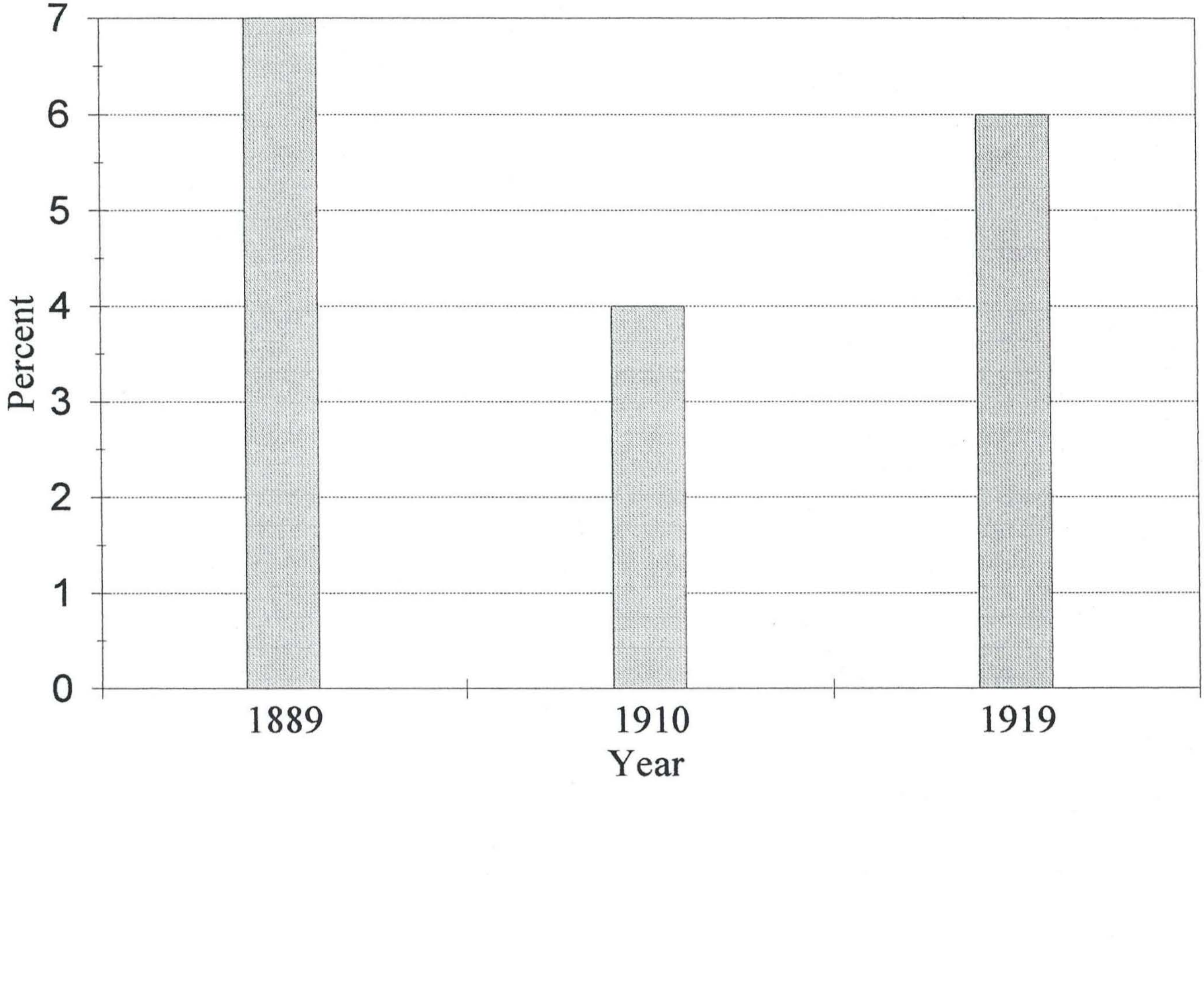
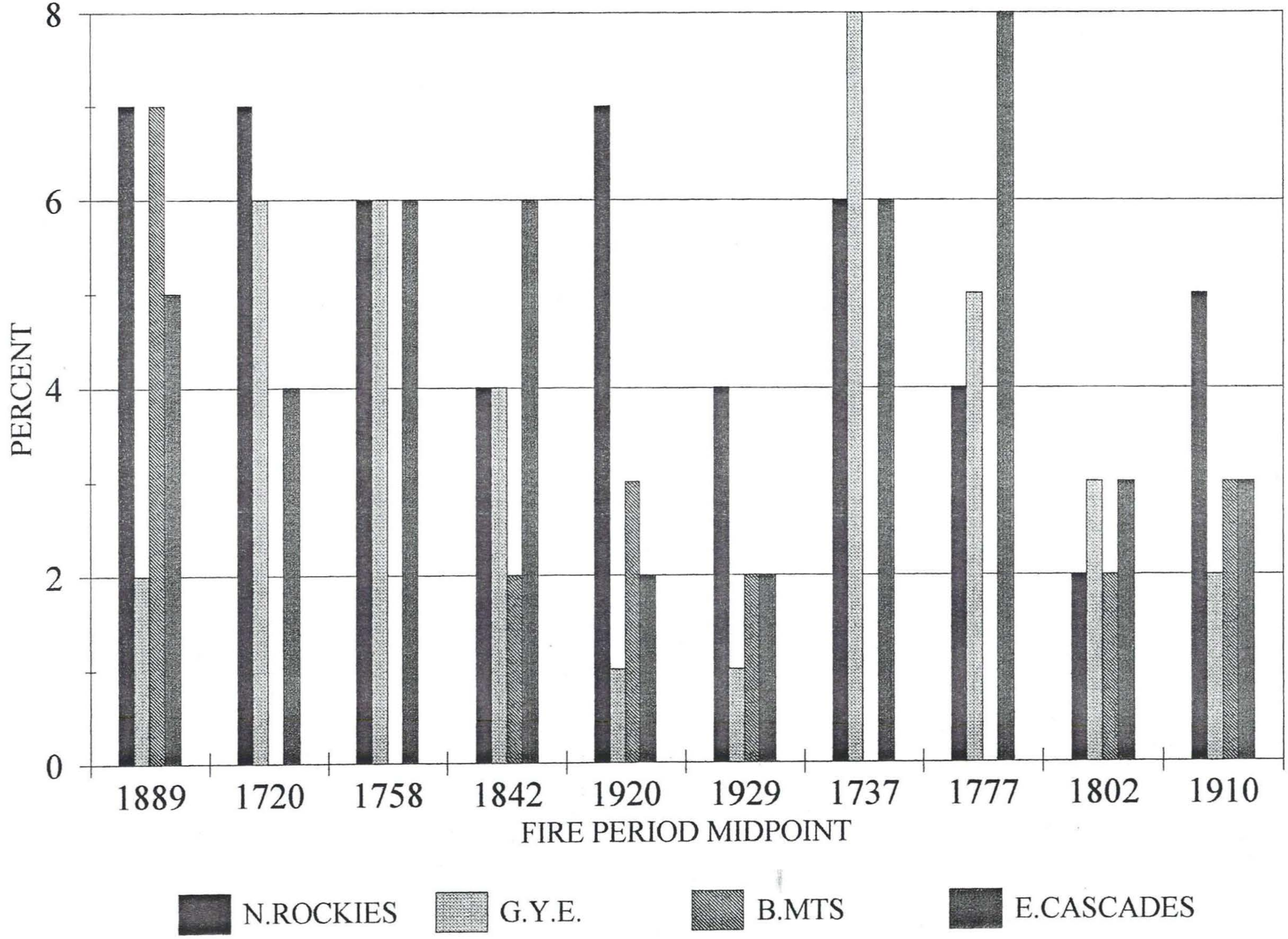


FIG. 10. FIRE PERIODS BY SUBREGION



APPENDIX A.

Fire History Bibliography (see also Appendix B).

(Note: For data location purposes, original draft reports are cited in place of any subsequent less-detailed publications. Applicable dBASE files: "RFIREYR.dbf"; "RFIREPUB.dbf").

DBASE
REF
NO.

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APPENDIX B.

Fire History References in Numerical Order (see also Appendix A).

1=Barrett (1984a) 2=Sneck (1977) 3=Arno (1976) 4=Barrett (1983) 5=Barrett (1986a) 6=Barrett (1981) 7=Buck (1973) 8=Dorey (1979) 9=Gruell et al. (1982) 10=Arno & Davis (1980) 11=Romme (1979) 12=Loope & Gruell (1973) 13=Houston (1973) 14=Tande (1977) 15=Hawkes (1979) 16=Barrett (1982) 17=Gruell et al. (1985) 18=Steele et al. (1986) 19=Gabriel (1976) 20=Marshall (1928) 21=Freedman & Habeck (1985) 22=Bakeman (1983) 23=Arno & Gruell (1983) 24=Pierce (1982) 25=Barrett (1988a)

26=Barrett (1985a) 27=Barrett (1986b) 28=Barrett (1987) 29=Arno (1985) 30=Arno (1981b) 31=Barrett (1992b) 32=Romme & Despain (1989) 33=Barrett (1991) 34=Barrett (1993a) 35=Habeck (1985) 36=Barrett (1988b) 37=Barrett (1990) 38=Barrett (1984b) 39=Taylor (1974) 40=Arno & Scott (1994) 41=Keane (1992) 42=Arno & Gruell (1986) 43=Arno (1981c) 44=Tymstra (1991) 45=Makela (1990) 46=Arno (1983) 47=Arno (1981a) 48=Arno (1975) 49=Ayres (1901) 50=Arno (1982)

51=Arno & Carlson (1986) 52=Arno (1977) 53=Arno et al. (1992) 54=Barrett (1993b) 55=Habeck (1972) 56=Barrett (1992b) 57=Losensky (1992) 58=USDA Forest Service Flathead National Forest Geographic Information System (1990) 59=Larsen (1925) 60=Johnson & Fryer (1987) 61=Masters (1989) 62=White (1985) 63=Barrett (1994c) 64=Losensky (1989) 65=Losensky (1987) 66=Idaho Daily Statesman (1889) 67=Gruell (1985) 68=Habeck (1992a) 69=Habeck (1992b) 70=Loope (1974) 71=Morgan & Bunting (1990) 72=Barrett (1994a) 73=Barrett (1994b) 74=Maruoka (1994) 75=Finch (1983)

76=Bork (1985) 77=Taylor (1983) 78=USDI Park Service Grand Teton National Park Fire Atlas (undated) 79=Burkhardt & Tisdale (1976) 80=Young & Evans (1981) 81=USDA Forest Service Region One Fire Atlas (undated) 82=Loope (1971) 83=Wischnofske & Anderson (1983) 84=Means (1980) 85=Hall (1980) 86=Losensky (1993a) 87=Losensky (1993b) 88=Losensky (1993c) 89=Losensky (1993d) 90=Agee (1991) 91=Mazany (1993) 92=McNeil & Zobel (1980) 93=Woodard (1977) 94=Bork (1984) 95=Zack & Morgan (1994) 96=Keen (1937) 97=Weaver (1959) 98=Dickman & Cook (1989) 99=Taylor (1993)

100=Weaver (1961) 101=Losensky (1993e) 102=Losensky (1993f) 103=Losensky (1993g) 104=Barrett (1994d) 105=Habeck (1994) 106=Cobb (1988) 107=Burke (1979) 108=Morrison & Swanson (1990) 109=Fahnestock (1977) 110=Soeriaatmadja (1966) 111=Allen (1994) 112=Hemstrom & Franklin (1982) 113=Arno (1994) 114=Pierce (1995a)

115=Pierce (1995b)   116=Pierce (1995c)   117=Pierce (1995d)   118=Pierce (1995e)
119=Pierce (1995f)   120=Pierce (1995g)   121=Morrow (1995)   122=Lehman (1995)

Appendix C.

Fire location maps for 34 peak fire periods in the greater CRB between 1540 and 1940 A.D.